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# Energy Use: Electricity System in West Africa and Climate Change Impact

**Abiodun S. Momodu***

*Centre for Energy Research and Development, Obafemi Awolowo University, PMB 024, Ile-Ife, 220005, Nigeria*

**ABSTRACT**

This article investigates a low carbon pathway, the theoretical frame for understanding the trade-offs between economic development and climate change. An already developed model – Electricity Planning-Low Carbon Development (EP-LCD) – was adapted and modified to examine the nonlinear relationship between generation adequacy and greenhouse gas (GHG) emission reduction for better targeted strategic regional intervention on climate change. Two broad scenarios – Base and LCD Option – were tested for the West African Power Pool (WAPP). The cost impact of increasing generation capacity in the LCD Option was estimated at US$1.54 trillion over a 50 year period. Achieving the goal of low carbon pathway would be largely influenced by government decision. Four strategies, in line with the Nationally Determined Contribution in Paris Agreement, were recommended. These are: a) enforced improved efficient electricity generation through increased energy efficiency that should result in increased capacity factor; b) decreased energy intensity of economic activities to result in reduced emission factor in existing plants; c) attract new investment through low tax or tax exemption to reduce cost of constructing power plants for the benefit of base-load plants; and d) subsidized cost of low-carbon fuels in the short run to benefit intermediate load plants and allow for the ramping up of low-/no-carbon fuel generation capacity. These are recommended considering the region's specific economical and political conditions where funds are tremendously difficult to raise. Implementing these recommendations will allow the electric power industry in West Africa to contribute to achieving sustainable development path.

***Keywords:***

Low-carbon-development;
Electricity;
System dynamics;
Climate change;
West Africa;

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## *1. Introduction*

Climate change is a complex, multi-faceted, and serious threat the world faces [1]. Tackling it requires an understanding of existing trade-offs with the economic growth required in large parts of the world. This will simultaneously advance developmental aspirations as well as address climate change impact. Low carbon development (LCD) pathways is explored for the West African electricity system, as a paradigm that contributes to addressing these twin challenges. This brief is prepared from a study [2] that evaluated the planning processes in the West African Power Pool (WAPP) electricity system vis-a-vis LCDs. The concept of Low Carbon Development Strategy (LCDS) was introduced by the Conference of Parties to the United Nations Framework Convention for Climate Change (UNFCCC). It represents a common but differentiated approach to meet the overall emissions reduction objectives.

West Africa (Figure 1) is made up of the 15 countries Benin, Burkina Faso, Cape Verde, Cote d'Ivoire, Gambia, Ghana, Guinea, Guinea Bissau, Liberia, Mali, Niger, Nigeria, Senegal, Sierra Leone, and Togo. Fourteen of these are located on the continent. The total

* Corresponding author e-mail: abiodunmomodu8@gmail.com; amomodu@cerd.gov.ng


Figure 1: Political map of West Africa [5]

population of West Africa was estimated at 353.2 million [3] in 2015. This population is very unequally distributed, with Nigeria holding over 52% of this, occupying a land space of only approximately 18% out of the total of 5,105 million km$^2$. The Africapolis study [4] reports an annual urban growth rate of 5.1% and a population growth rate of 4.3% between 1950 and 2000 for West Africa. The report went further to categorize the region as one of the least urbanized in the world, partially because it is also one of the least industrialized and poorest in terms of economic resources. Going further, a World Bank ranking of the WAPP countries amongst 217 global economies by the gross domestic product (GDP) shows that only Nigeria is ranked amongst the first 30 global economies, with only two more ranked amongst the first 100 economies while the remaining countries in the WAPP fall in the range of 100$^{th}$ to 195$^{th}$ global economies. In per capita terms, the poorest country in the WAPP is Niger, which was ranked 144$^{th}$ in the world, with $359/capita in 2015. The "richest" country, Nigeria, in the 23$^{rd}$ place with GDP per capita of $2,672 [6]. Over the last few years, the local economy of some of the WAPP countries (Nigeria, Liberia, Guinea, Mali) have suffered badly from financial, political and social turmoil [4].

Low levels of urbanization and high levels of poverty go hand in hand with low populations in many countries: Guinea Bissau, Gambia, Liberia, Togo, and Sierra Leone all have fewer than 5 million inhabitants. Because of this combination of low levels of urbanization and wealth, the urban markets of West Africa are insignificant when seen on a global scale. According to the World Bank, the region in 2015, had a combined GDP estimated at US$628 billion, which was barely 3% of that of USA with an almost similar population size in the same period. The economy of West Africa is coordinated under the aegis of ECOWAS (Economic Community of West African States), established in 1975.

In terms of energy, West Africa's strategic resources include hydro-electricity, oil, natural gas and coal. These are unequally distributed in the territory. Additionally, aside from its hydro sources, the region is endowed with other renewable energy sources such as solar insolation, bio-energy and wind. However, despite being endowed with these energy resources, access to electricity in the sub-region has remained at less than 50% in the urban areas and less than 20% in rural areas. Energy use, particularly electricity is projected to rise in the nearest future. At an average economic growth rate of about 6% annually, the demand for electricity is projected to grow in the same or higher proportion. The implication is obvious as regards GHG emissions, depending on the choice of the mix of power plants that would be needed to meet the future demand for electricity [7]. It is in realization of the need to harness and efficiently utilize its energy resources for development that it (ECOWAS) established the West African Power Pool in 1999, which became operationalized in 2006 [7].

The WAPP, which is a specialized institution of ECOWAS is the institutional framework of the regional electric system. The strategic objective of the WAPP is based on a dynamic vision of the integration of the operation of the national electricity networks in a unified regional market. This unified regional market must make it possible to ensure in the medium and long term an optimal electricity supply, reliable and at an affordable cost to the population of the various member states [7]. West African electricity system currently has an installed capacity of 17,155 MW, out of which available capacity was 10,094 MW in 2015 [8]. Installed capacity is the nameplate/rated/nominal capacity representing the intended full-load sustained output of a power plant in the power system. On the other hand, available capacity is the maximum amount of power that the system is capable of generating in a given period. The large difference between installed and available capacity in the case of West Africa power system is attributed to age of generation stock which in turn affects their efficiencies and produce high energy intensity.

The WAPP system has only four electricity technology types in its generation stock, categorised based on fuel. The technologies within these fuel types also vary in terms efficiency, emission and capacity factor. The current composition as of 2015 shows that oil contributes about 14%, coal, 0.3%, natural gas, 48.5% while hydro make up the rest with 37.2% [2] of production. Nuclear is currently not among the mix of generation technologies. It is noted that anthropogenic greenhouse gas (GHG) emissions are mainly driven by population size, economic activity, lifestyle, energy use, land-use patterns, technology and climate policy [9]. Meaning, new approaches, such as low carbon pathway being examined in this article, are needed to control future emissions [9].

### 1.1. Statement of problem

Rapid transformation involving adequate provision of critical infrastructure such as energy including electricity for socio-economic development is needed by West Africa member states. To avoid pre-industrialization trajectory*, this will demand ample understanding of the trade-offs between economic growth and development aspiration on the one hand, and climate change issues on the other. Arguably, the sub-regional desire to develop should precede that of global environmental concern in ranking; however, it is important that this developmental pursuit be done with some sense of responsibility to the environment [10]. This is the underlying principle behind the Paris Agreement to which all WAPP member countries are signatories.

Though large-scale economic development is needed to pull millions of citizens out of abject poverty, a "business-as-usual" approach would exacerbate the problem of climate change with potentially irreversible long-term consequences. With these factors affecting anthropogenic emissions, West Africa sub-region, though considered amongst the Non-Annex 1 countries*, could well become a prime source for future GHG emissions except if its policy makers adopt strategic intervention for the energy consumption agenda and climate change mitigation. This is to meet economic development from future demand and avoid the same trajectories as those of developed countries [11, 12, 13]. According to [5], "business-as-usual" are projected for Non-Annex I emissions in the absence of any new climate policies to control emissions. These projections however shows that by 2050, emissions in all Non-Annex I regions would need to be substantially reduced below "business-as-usual". For West African countries, without any strategic intervention, the quest to increase generation capacity in the power sector would definitely take the same trajectories as those of developed countries and cause undesired increase in the release of GHG emissions to the atmosphere [11, 12, 13].

LCDSs have attracted the interest in the climate negotiations as a soft alternative to voluntary or obligatory GHG emission reduction targets in developing countries as it also represents the concept of Nationally Determined Contribution (NDC) to emission reduction [11]. Although there is no internationally agreed definition of LCDSs, this article focuses on policy of integrated climate and (low-carbon) development strategies that cover the intersection of development and GHG mitigation in West Africa power sector. Low-carbon development strategies represent a different planning paradigm from what used to be the norm in planning the power sector [14, 15, 16]. In line with this global expectation, it becomes important to develop LCDS for the power sector, a critical infrastructure in West African sub-region for sustainable development.

### 1.2. Objective

West African nations are evolving, and need energy to drive their various economic activities. Energy drives economic development, and in turn, economic development drives the need for more energy usage. It is imperative to therefore understand how the energy use of these nations will evolve at the different stages of their development as an essential means of having a reliable prospective analysis and planning. This study is intended as a decision support tool for WAPP future electricity consumption in examining the push-pull factors of the system as regards climate change. It is well reported that the relationship between electricity consumption and economic growth is non-linear [17, 18, 19, 20, 21]. Also, literature on development history across countries have usually shown an 'S-shaped' (sigmoid) relationship between per capita electricity consumption and per capita GDP [22, 18]. Systems that exhibit S-shaped growth behavior are

* This simply refers to the path that has had predominantly fossil-fuel based energy technologies ,

* Non-Annex I Parties are mostly developing countries without any obligation to meet any defined emission target under the Kyoto Protocol.

characterized by constraints, or limits to growth [23]. By this growth, two points of inflexion are indicated, which, in terms of electricity development, the first corresponds to the transition from non-industrial to industrializing stage, in which increase in economic growth leads to a more proportionate growth in electricity consumption. The second inflexion point corresponds to where economic growth rate would become de-linked from electricity consumption because of two major factors. First, the structure of the economy at this point is dominated by the service sector as shown in the case of industrially developed countries; and second, due to increase in energy efficiency [24].

To avoid previous-industrialised GHG emission trajectory, nations in West Africa, which are the Non-Annex 1 countries, would need to adopt strategic intervention in energy consumption by understanding the trade-offs between the variables of energy and economy. This challenge makes the use of System Dynamics (SD) as the modelling tool with its non-linearity capacity important to examine these factors. SD has the capacity to endogenously alter the active or dominant structure of a system and shift loop dominance. Given the expected S-shaped growth trend in the economy of West Africa, will its electricity development have to rise to eventually reach the level of that of developed countries or will it peak at a certain level in its development path? What will be the implication of this growth path to emission from the electricity industry? The answers to these questions could be useful in adjusting policies towards attaining sustainable development path in the WAPP. This informs the objective of this article: to provide policy decision support system in energy consumption agenda and climate change.

## 2. Energy consumption and GHG emission pattern in West African countries

A number of studies have been conducted as regards electricity and climate change in West Africa. A study by Gnansounou et al [25] examined strategies on electricity supply and climate change, reporting on the evolution of regional electricity market on the basis of two strategies – "autarkical" and "integration[†]". It recommends integration strategy as it leads to fast retirement of the aged power plants and the integration of new investment projects to bring about additional benefits in terms of reduced capital expenditures, lower electricity supply cost and the enhanced system's reliability compared to the autarkical strategy. It did not examine the climate change and cost impacts. Another study on WAPP [26] develop models to understand the long-term interactions between investment and performance in the electric power system. It shows that WAPP interconnection has a clear impact on the local system prices and investments in new construction but there will still be large regional variations in prices and new construction. A third study [27] assesses extreme temperatures and heat waves impacts on electricity consumption in some cities in West Africa. It reports that electricity consumption trends in the cities examined match extreme temperatures evolution well. An SD study [15] examines trade-offs between economic growth and climate change that provides the context to explore LCD pathways for the West African electricity system. It identifies four high leverage points that could serve to achieve LCD in the WAPP.

In terms of consumption, Table 1 shows the 2015 installed generation and available capacity and GHG emission factor for countries of West Africa. Nigeria had the highest installed and available capacity. This is followed by Ghana and Cote d'Ivoire respectively. Based on available data for 2015, the least electrified and GHG emitting country is Liberia. However, in examining the countries through the lens of per capita consumption as represented in Figure 2, a different hierarchy emerges. The highest per capita electricity generation country is Ghana at 469 kWh/person and GHG emission of 0.153 $tCO_2eq$/capita, followed by Cote d'Ivoire with 333 kWh/person and 0.108 $tCO_2eq$/person. Though Senegal has the third highest per capita electricity generation, it has the second highest per capita emission rate at 0.134 $tCO_2eq$. This therefore shows that for better targeted strategic regional intervention on climate change, detailed examination of micro production/consumption of electricity is essential. Micro production/consumption means taking the effects of consumption into consideration in the choice of generation technology. As Nigeria contributed significantly to the WAPP electricity generation, its per capita consumption is critical to keeping emission at a controllable level. This immediately presents an opportunity to examine improvement in capacity and emission factors from the power plants in the member countries of WAPP.

[†] Autarkical refers to something that is free from external control and constraint, or independent; while integration refers to something dependent or not constrained.

**Table 1: Installed and available capacity, average emission factor, capacity life time and time to adjust capacity in West African countries in 2015 – Base Scenario Data**

| Country | Installed Capacity, [MW] | Available capacity, [MW] | Average Emission Factor of Power Plants, [$tCO_2$/MWh] | Capacity Lifetime [Years] | Time to Adjust Capacity [Years] |
|---|---|---|---|---|---|
| Benin | 205 | 134 | 0.563 | 25 | 20 |
| Burkina Faso | 219 | 135 | 0.693 | 25 | 21 |
| Cote d'Ivoire | 1,632 | 1,195 | 0.326 | 25 | 20 |
| Gambia | 100 | 39 | 0.777 | 25 | 21 |
| Ghana | 2,814 | 2,185 | 0.326 | 25 | 20 |
| Guinea | 203 | 109 | 0.793 | 25 | 21 |
| Guinea Bissau | 0 | 26 | 0.728 | 25 | 20 |
| Liberia | 23 | 22.6 | 0.568 | 25 | 21 |
| Mali | 220 | 86 | 0.580 | 25 | 20 |
| Niger | 164 | 138 | 0.867 | 25 | 21 |
| Nigeria | 10,915 | 5,061 | 0.578 | 25 | 20 |
| Senegal | 683 | 468 | 0.817 | 25 | 21 |
| Sierra Leone | 0 | 0 | 0.568 | 25 | 20 |
| Togo | 224 | 180 | 0.952 | 25 | 21 |
| Total | 17,155 | 9,550 | | | |

*Sources: [7], author estimation*

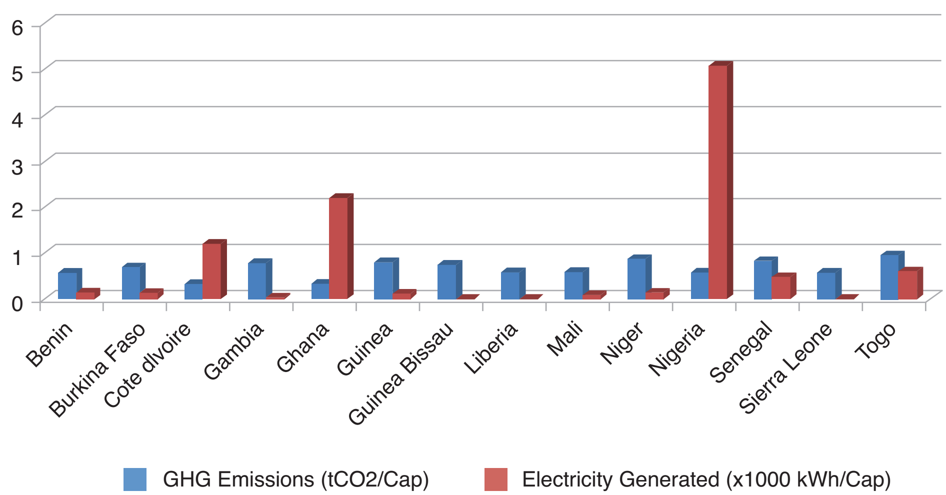


Figure 2: Per capita electricity generation versus per capita GHG emission [8]

## 3. Methodology

### 3.1. Data collection

Table 1 represents WAPP member country level data as the set of basic data used to develop and run the main model (Figure 3) used in analysis in this article. These data were elicited from secondary sources, principally with institutions in West Africa related to electricity provision and regulation, namely, WAPP and ECOWAS Regional Electricity Regulatory Authority (ERERA). Other data elicited include population and its average growth rate, GDP, per capita income, average per capita electricity demand, electricity generated, average electricity tariff, generation technology type, amongst others. All these data are used on a model developed based on System Dynamics to examine the (nonlinear) relationship between generation adequacy and GHG emission reduction in the WAPP. The model evaluates the tension between providing adequate supply capacity against reducing emission from the

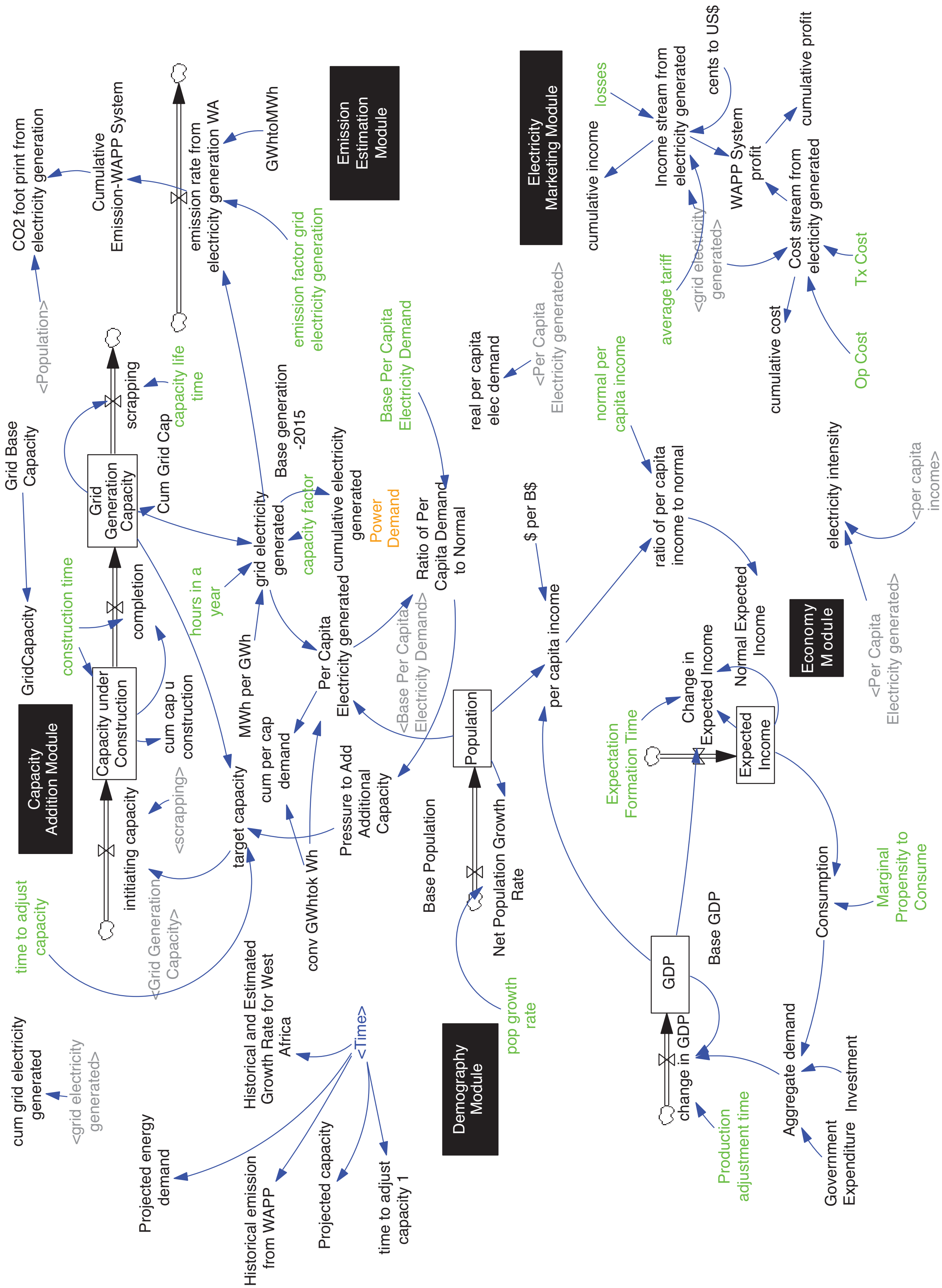


Figure 3: Electricity Planning-Low Carbon Development V1 Model (adapted from Momodu et al [2]

generation technologies in the West Africa electricity system. It arranged the complexities in the West African electricity system and established its basic interconnecting structure to conduct the analysis, in line with global expectations for reduced emission and achieve economic growth.

### 3.2. Model development

For this study, the Electricity Planning – Low Carbon Development (EP-LCD) Model [2] was adapted and modified with its conceptualization based on [28, 29]. This is called EP-LCD v1 shown in Figure 3. To develop the structure, the boundary was set around electricity supply, generation and marketing, population and the GDP. To incorporate the study objective into the model, the study relied on a review of the operations of the WAPP electricity system as described in Article 1 of the WAPP establishing document as well as WAPP's vision and mission that aims to make the electricity system in the ECOWAS sub-region to be operated as a merchant power market when enabling environments for this kind of operations is achieved [30, 31]. The EP-LCDv1 model (Figure 3) is largely focused on electricity operations and interconnections in the WAPP power system as well as GHG emitted from the system. The power system examined emission from the basis of generation and average emission factor as well as based on generation technology types.

The dynamics are described by a set of non-linear differential equations that account for existing system feedbacks, delays, stock-and-flow structures and nonlinearities. The model is distinguished by the manner in which various sectors and spheres are connected together to form a complex link of feedback loops in which the electric system can be analyzed and weighted as driving or limiting the county's LCD agenda. (The set of equations used in the model can be found in the appendix).

A major principle in the developed SD model is the leverage points. Leverage points are places within a complex system (a corporation, an economy, a living body, a city, an ecosystem) where a small shift in one thing can produce big changes in everything [32]. Leverage points are points of power in a system that modelers not only believe in but would want to know where they are and how to locate them. There are steps to help identify places of intervention in a system [31].

The "state of the system" – electricity, a nonmaterial commodity – in whatever standing stock is of importance. The inflow – electricity generation, investment and financial flow – increase the stock, while the outflow – transmission, distribution, losses and thefts – decrease it. So the bedrock of this system consists of physical stocks and flows, obeying the laws of conservation and accumulation. Now the challenge in the WAPP power system is principally inadequacy; meaning that the inflow rate is lower than the outflow rate, making the non-storable commodity be in shortfall always.

It takes time for systems to respond to desired growth as is typical for flows to accumulate. Same thing with the electricity system in WAPP, it will take time to correct the anomalies making it to be sluggish in responding to desired changes. It is critical, however, to be able to identify the 'leverage points' along the line of the operations of the electricity system in WAPP with the superimposed LCD models and the corrective measures to achieve desired objectives as enunciated in the objectives, vision and mission of WAPP.

Systems have at least two negative feedback loops, or correcting loops [32]; one controls the inflow, and the other one controls the outflow, either or both of which can be used to bring the system to a desired level. It is important to point out that the goal and the feedback connections are not visible in the system. However, a long-term view of the system will enable one to figure out what are the leverage points in it. Now, this study involves superimposing a new paradigm – LCD – into the planning of an already complex system in WAPP, to bring out future plan that is responsive to delivering electricity that is globally cost competitive and also achieve desired reduced emission.

### 3.3. Brief description of model workings

As an approach to understanding complex systems and their dynamic behavior, SD was used to model the West African Electricity System as it relates to other sectors. The different sectors are segmented as modules in EP-LCDv1 model as presented in Figure 3. The model was built in Vensim® using basic SD variables. It analyzed low carbon emission in the West Africa electricity system. Explaining variables is often difficult without reference to equations, but it is useful to have a complete categorization and specify conventions. Vensim® is designed so that what a variable is and does can be determined by the way it is defined or used. Vensim® has eleven variable types [33], but only those used to develop the model for this study are described here.

a. **Auxiliary.** Any dynamic variable that is computed from other variables at a given time. Auxiliaries are typically the most numerous variable type. An auxiliary variable has an expression involving other variables in its equation.
b. **Constant.** A variable whose value does not change over time. A constant can be temporarily changed prior to simulating a model.
c. **Initial.** Like a constant, except that it is the result of combining different variables at initialization time.
d. **Level.** The dynamic variables in the model. Levels all have integral (INTEG) equations.
e. **Lookup.** Nonlinear functions with numerical parameters (where the parameters are the x- and y-axis values).
f. **Subscript Element.** An element of a Subscript Range. These identify the meaning of specific values of a subscript. The Subscript Elements appear on the right hand side of a Subscript Range equation.
g. **Subscript Range.** Rather than repeating the same equation with different names, an one equation can be written using a subscript that takes on different values. This variable type is referred as subscripted, with one name representing more than one distinct concept. Subscript Ranges are defined using a special equation that begins with a colon (:)
h. **Units.** Units are defined as additional information about a model variable and can be used to check the model for dimensional consistency. Units are entered as an expression in the units field of an equation.
i. **Unchangeable Constants.** These are Constants that cannot be changed during simulation experiments. Constants and Unchangeable Constants are almost the same. The only difference is that the value for an Unchangeable Constant is determined from its equations, or read from a spreadsheet when a model is checked, and never changed after that.

The model consists of interconnections of three different sectors. The sub-sectors, namely, electricity (split into capacity addition (MW) and power demand (GWh)), demography (principally the population) (Persons), economy as depicted by the gross domestic product (GDP) (Billion US$), make up the three modules in the model. There are two sub-modules in the model as offshoot from the power demand segment under the electricity module. These are: emission from electricity consumption ($tCO_2$) and electricity marketing (US$). For this article, analysis of results from the model was limited to only the electricity module as data needed from other two modules narrowed the integrity of their results.

Each of the modules has at least one Level variable with integral equation. Most level variable equations in Vensim® software take the form of:

**Level Variable (Name) =** *(inflow(t) – Outflow(t), initial_value(0)*

Level variables represent stocks in system dynamic models. This means that all the Level variables in the model, namely, Population, GDP, Capacity under Construction, and Grid Generation Capacity are stock operating the Principle of Accumulation*, and take on the form of Equation (1) to run in the model. Now, the critical aspect of Level variable is that it allows for the introduction of the concept of delay, a dynamic function, into the system being modeled. Being stocks, these variables have four important characteristics of having memory, changing the time shape of flows, decouple flows and create delays. The concept of delay is expatiated upon elsewhere [36]. One of the principal equation is that of Grid Generation Capacity as represented thus:

**Grid Generation Capacity [WAPP Member Countries]** = ∫(completion [WAPP Member Countries]– scrapping [WAPP Member Countries], Grid Base Capacity [WAPP Member Countries]), Units: MW.

What is placed in the [X] shows the subscripts to the equation. This allows one variable and equation to represent a number of different distinct concepts.

The grid segment has capacity under construction to reflect how capacity is increased over the years. The grid capacity segment also has scrapping, which is driven principally by capacity life time (Years). The critical aspect of the capacity under construction is the assessment of initiating capacity, which in turn is driven by target capacity (MW) and time to adjust (Years). The target capacity is driven by per capita power generation in the system. The per capita power generation (kWh/Person) in the system is assumed to be driven principally by population (this is derived from the demography segment of the model). (In a fully liberalized market, this is expected to be determined by investor behavior – e.g. see [36]).

It is important to state that the modules in the model are subscripted. Subscript in the modules allowed a

* Accumulate: growing or increasing over time (Source: [38])

variable (e.g. grid capacity, birth rate, GDP, etc) to represent more than just a data for the variable. In this model, the subscript dealt with WAPP member country level information as well as aggregation of generation technology types in the WAPP.

### 3.4. Scenario development and sensitivity analysis

Parameters within the model forms the basis for developing the scenarios for analysis. For this study, two scenarios on the WAPP electricity system, Base Case and LCD Options, are analyzed. The Base Case scenario represents continuing a "business-as-usual" approach that draws on technologies in the electricity system as they currently are. No consideration is given for efficiency and how these technologies fare in terms of contribution to global warming through emission of GHG into the atmosphere. The LCD Options on the other hand, draws on technologies with higher efficiency and low carbon emission to replace generation technologies that have high emitting factors. The LCD Option is examined based on changes in two parameters, namely, capacity and emission factors, against two different values of per capita electricity generation levels respectively. Other parameters are kept constant as in Base Case Scenario. To improve on the WAPP system, the LCD Option 1 was assumed to have emission factor improved by 10%, meaning EF is reduced by a factor of 0.1 from that of the Base Scenario, for each of the plants, while for LCD Option 2, it is reduced by a factor of 0.3.

The model is made up of seven subscripted parameters, with the Base Case values listed in Table 1 being country level data and Table 2 being aggregated technology type in the WAPP. The high leverage points for policy intervention were identified from Tables 1 and 2. High leverage points are places within a complex system (a corporation, an economy, a living body, a city, an ecosystem) where a small shift in one thing can produce big changes in everything [32]. Further testing – sensitivity analysis – could be conducted on the model. The high leverage points form the basis for constants to conduct the sensitivity analysis. Sensitivity testing is the process of changing assumptions about the value of constants in the model and examining the resulting output [39].

With multiple parameters identified in the model as high leverage points in the model, the multivariate sensitivity simulation (MVSS) or Monte Carlo simulation is a natural choice. Four high leverage points identified in the West African electricity system are capacity factor (CF), emission factor (EF) (country average and technology type), time to adjust capacity and expectation formation. In running of the model, two parameters stood out on their effect on generation capacity addition and GDP.

Literature is scarce on the issue of time to adjust capacity, which is similar to expectation formation time, therefore an explanation of these parameters is given briefly. For time to adjust capacity, usually a number of steps are taking to manage the load in a grid system. This is known as load management or demand side management. This is simply the process of balancing the supply of electricity on the network with electrical load by adjusting or controlling the load rather than the power output. However, due to the fact that generators in the network will at a time or the other come to the end of their lifetime and be disengaged from service, it is critical to also determine the time to adjust capacity. Time to adjust capacity refers to the time in planning for generation capacity when new capacity must be planned

**Table 2: Base Case Parameters in the EP-LCD model**

| Fuel / Technology Type | Capacity (MW) | Capacity factor (Dmnl) | Capacity Lifetime (Years) | Constru-ction time (Years) | Emission factor ($tCO_2$/MWh) | Normal Per Capita Electricity Demand (MWh/Cap) | Time to Adjust Capacity (Years) |
|---|---|---|---|---|---|---|---|
| Residual Fuel Oil | 1410 | 0.48 | 25 | 3 | 0.2786 | 0.146 | 20 |
| Gas | 4892 | 0.58 | 25 | 3 | 0.2020 | | |
| Hydropower | 3760 | 0.54 | 50 | 10 | 0.0 | | |
| Coal | 32 | 0.48 | 25 | 8 | 0.3413 | | |
| Nuclear | 0 | 0.40 | 25 | 10 | 0 | | |

*Sources: [1, 31, 34, 35]*

for and be added to existing capacity to avoid overstretching the installed capacity. This is usually signaled by tight reserve margin. Reserve margin [38] is what the electricity utility industry employs as a simple strategy for maintaining reliability, i.e., always have more supply available than may be required. Yet it can be difficult to forecast future electricity demand, and building new generating capacity can take years.

The industry regularly monitors the supply situation using a measure called reserve margin. Reserve margin is capacity minus demand)/demand, where "capacity" is the expected maximum available supply and "demand" is expected peak demand. It is calculated for electric systems or regions made up of a number of electric systems. For instance, a reserve margin of 15% means that an electric system has excess capacity in the amount of 15% of expected peak demand [38]. For this study, the sensitivity analysis has not been conducted in the model.

## 4. Result and analysis of model output based on different scenarios

Comparison of the result from running the model at Base Case and LCD Options (1 and 2) respectively is presented in this section. The model was run in time space of 50 years, with 2015 as the base year and 2064 as the terminal year. The values for LCD Options parameters for the model are presented in Table 3, with its implication explained in section on low carbon development strategy in WAPP. After establishing the model structure and unit checks made, it was further validated using values gotten for WAPP in an independent study [40].

The expectation formation periods were determined at 7.5 years for the Base Case Scenario and 7 years for the LCD Option scenario. Time to adjust capacity was located at 21 and 20 years respectively, deduced from the average time it will take to construct a combined cycle gas power plant (3 years) and an allowance of 2 years for delays and its decommissioning time. In reality, these times (expectation formation and time to adjust) are missing in operating most of the power systems in the region. For example, out of the 24 documented power plants in Nigeria, only 14 were built as recent as 30 years or less ago. These power plants are only 48% of the total generation capacity, with no immediate plans of their replacement.

Table 4a shows the ranges of future generation capacity in MW with projected electricity to be generated from this capacity as well as the emissions measured in billion MWh and tonnes of $CO_2$ respectively. Table 4b gives the assumptions made for each of the scenario options using 2015 as the reference year.

From the model run, weighted average emission of GHG was 27.1 million $tCO_2$ equivalent for the Base Scenario in the 50 year period. For the two LCD Options, the average weighted average annual emissions

**Table 3: LCD Option Parameters in the EP-LCDv1 model**

| | LDC Option 1 | | LCD Option 2 | |
|---|---|---|---|---|
| **Country** | **Average Emission Factor of Power Plants, [$tCO_2$/MWh]** | **Average country plant capacity Factor, [$tCO_2$/MWh]** | **Average Emission Factor of Power Plants, [$tCO_2$/MWh]** | **Average country plant capacity Factor, [$tCO_2$/MWh]** |
| Benin | 0.5067 | 0.756 | 0.3941 | 0.81 |
| Burkina Faso | 0.6237 | 0.756 | 0.4851 | 0.81 |
| Cote d'Ivoire | 0.2934 | 0.728 | 0.2282 | 0.78 |
| Gambia | 0.6993 | 0.784 | 0.5439 | 0.84 |
| Ghana | 0.2934 | 0.756 | 0.2282 | 0.81 |
| Guinea | 0.7137 | 0.798 | 0.5551 | 0.855 |
| Guinea Bissau | 0.6552 | 0.756 | 0.5096 | 0.81 |
| Liberia | 0.5112 | 0.756 | 0.3976 | 0.81 |
| Mali | 0.522 | 0.756 | 0.406 | 0.81 |
| Niger | 0.7803 | 0.672 | 0.6069 | 0.72 |
| Nigeria | 0.5202 | 0.742 | 0.4046 | 0.795 |
| Senegal | 0.7353 | 0.812 | 0.5719 | 0.87 |
| Sierra Leone | 0.5112 | 0.672 | 0.3976 | 0.72 |
| Togo | 0.8568 | 0.812 | 0.6664 | 0.87 |

*Sources: author's assumption*

is 31.5 and 15.8 million $tCO_2$ equivalent respectively. The cumulative emission for the scenarios are 1.4, 2.2 and 0.8 billion $tCO_2$ respectively. Adopting the strategy of improved capacity and emission factors of these aged plants achieved significant reduction in emission levels as seen in the LCD option 2.

### 4.1. Traditional Economy versus Low Carbon Economy in the Electricity System

The Paris climate change agreement entered into force on November 4, 2016, with 197 parties having ratified, accepted, approved or acceded to its instruments with the depositary. By signing the agreement, the countries committed themselves to reducing *Greenhouse Gas Emissions unconditionally by 20 per cent and conditionally by varying percentage in line with their Nationally Determined Contributions (NDC).*

Some countries and regions of the world have repositioned their electricity sector to meet global challenges. This is one area amongst many that the Paris Agreement could be effected at low cost through focus on LCD strategy. The countries in the WAPP have ratified, accepted, and approved the agreement. So to achieve the NDC in West Africa, this deliberate strategic process could be adopted as a low-hanging option to contribute to the reduction of global warming.

Electricity expansion in West Africa targets un-served areas to expand access. The cheapest means of this expansion is the use of fossil fuels. Taking this path to economic growth (industrialization process) unmitigated, will aggravate the already felt climate change impact in the sub-region. This could be with irreversible consequences. The fact really is that most of the current policies for developments in the sub-region are premised on the framework used in pre-industrialization era. To avoid the after-effect of such policies, it is important that the WAPP system pursues a developmental agenda that responds adequately to global climate change obligations as well as meet with this projection of future generation requirements.

So WAPP as a cooperation system for electricity generation, would need to incorporate the strategies of low carbon development (LCD) in its operations to achieve a balance between development and GHG emissions .

In this way, firstly, the critical challenge of the sector to achieve reduced GHG emission is addressed. Secondly, the strategies are developmental in that they will allow for increased energy access and consumption, incorporating acceptable regulatory option(s) to improve standard of living in the long-run. The generation capacity examined in the model is only that of the available capacity and not the installed capacity.

**Table 4a: Ranges of future generation capacity (MW), electricity generation (MWh) and $CO_2$ emissions ($tCO_2$)**

| Scenario | 2015 | 2030 | 2064 |
|---|---|---|---|
| Base | 9912 | 8974 | 13718 |
| LCD Option: 1 | 9912 | 12108 | 31049 |
| LCD Option: 2 | 9912 | 12108 | 31049 |
| Base | 29368 | 26535 | 40366 |
| LCD Option: 1 | 44051 | 53797 | 137838 |
| LCD Option: 2 | 44051 | 53797 | 137838 |
| Base | 15.3 | 13.8 | 20.9 |
| LCD Option: 1 | 18.3 | 22.5 | 57.1 |
| LCD Option: 2 | 16.1 | 19.6 | 50 |

**Table 4b: Some assumptions made to estimate ranges of future generation capacity, electricity generation and $CO_2$ emissions**

| Assumptions | | | |
|---|---|---|---|
| Average per capita electricity consumption for WAPP countries, MWh/cap | Base | 115 | Reference year: 2015 |
| | LCD Option: 1 | 363 | |
| | LCD Option: 2 | 611 | |
| Average capacity factor for countries, ratio | Base | 0.54 | Reference year: 2015 |
| | LCD Option: 1 | 0.75 | |
| | LCD Option: 2 | 0.81 | |
| Average emission factor for WAPP countries, $tCO_2$/MWh | Base | 0.6526 | |
| | LCD Option: 1 | 0.5221 | |
| | LCD Option: 2 | 0.4568 | |
| Expectation formation, years | Base | 7 | |
| | LCD Option: 1 | 7.5 | |
| | LCD Option: 2 | 7.5 | |
| Time to adjust capacity, years | Base | 21 | |
| | LCD Option: 1 | 21 | |
| | LCD Option: 2 | 21 | |

For instance, Nigeria has an installed capacity of about 12,500 MW but can only have an available capacity of only about 40% of that to generate electricity. The reasons for the low level capacity utilization are traceable to incessant gas shortages, ill-maintained power plants, weak transmission capacity [41], vandalism, obsolete distribution network, amongst others. By merely assuming an increased capacity factor of 0.5 to that of the Base Scenario value (i.e. CF>0.5Base), the change in generation rose significantly as shown in Table 4a.

### 4.2. Low Carbon Development Strategy in WAPP

To achieve development, energy consumption would need to be increased. This means expansion of grid capacity in generation, transmission and distribution. So at first glance as shown in Table 5, development policies will be running counter to reducing GHG emission . Thus to counter such direction is to apply low carbon development strategy. This strategy will handle tension between achieving development and reducing GHG emissions from infrastructural provision. That is, LCDS will achieve needed trade-offs between development policy and climate policy. LCDS is counterintuitive, taking cognizance of the existence of negative feedback loops. This is demonstrated in the result shown in Table 5. The Base Scenario guided how mitigation targets were set.

To examine low hanging options available for achieving LCDS in the WAPP electricity system, the two other alternatives were ran for the LCD Option, namely, LCD Option 1 and 2 scenario. The first alternative considered increased efficiency in the generation capacity by a factor of 50%, through improved average capacity factor across the countries.

The second alternative, considered reduced emission through reducing average emission factor across WAPP member by 30%. This is in addition to the strategy adopted in LCD option 1. In the first alternative, the system gained increased energy generation, though with

**Table 5: Results for generation capacity in the Base and LCD Option 1 & 2 Scenarios**

| Country | Scenario | 2015 | 2025 | 2030 | 2035 | 2045 | 2055 | 2064 |
|---|---|---|---|---|---|---|---|---|
| Unit | | MW | | | | | | |
| Benin | Base | 134 | 110 | 117 | 125 | 142 | 162 | 181 |
| | LCD Option | 134 | 141 | 164 | 191 | 259 | 351 | 461 |
| Burkina Faso | Base | 135 | 105 | 110 | 115 | 126 | 137 | 149 |
| | LCD Option | 135 | 136 | 155 | 177 | 231 | 301 | 383 |
| Cote d'Ivoire | Base | 1195 | 926 | 936 | 947 | 968 | 990 | 1010 |
| | LCD Option | 1195 | 1173 | 1295 | 1430 | 1743 | 2125 | 2541 |
| Gambia | Base | 39 | 28 | 26 | 25 | 23 | 21 | 19 |
| | LCD Option | 39 | 35 | 37 | 38 | 42 | 45 | 49 |
| Ghana | Base | 2185 | 1797 | 1916 | 2042 | 2321 | 2637 | 2959 |
| | LCD Option | 2185 | 2301 | 2679 | 3118 | 4225 | 5724 | 7524 |
| Guinea | Base | 109 | 85 | 89 | 93 | 102 | 111 | 120 |
| | LCD Option | 109 | 110 | 125 | 143 | 187 | 243 | 309 |
| Guinea Bissau | Base | 26 | 20 | 20 | 21 | 21 | 22 | 22 |
| | LCD Option | 26 | 26 | 28 | 31 | 38 | 46 | 55 |
| Liberia | Base | 23 | 18 | 18 | 19 | 21 | 23 | 25 |
| | LCD Option | 23 | 23 | 26 | 30 | 39 | 50 | 64 |
| Mali | Base | 86 | 64 | 62 | 60 | 56 | 53 | 50 |
| | LCD Option | 86 | 80 | 85 | 90 | 101 | 113 | 126 |
| Niger | Base | 138 | 102 | 102 | 101 | 100 | 98 | 97 |
| | LCD Option | 138 | 130 | 141 | 153 | 181 | 213 | 247 |
| Nigeria | Base | 5061 | 4595 | 4928 | 5285 | 6079 | 6993 | 7932 |
| | LCD Option | 5061 | 5569 | 6422 | 7406 | 9848 | 13096 | 16926 |
| Senegal | Base | 468 | 333 | 318 | 304 | 278 | 254 | 234 |
| | LCD Option | 468 | 480 | 529 | 582 | 705 | 853 | 1014 |
| Sierra Leone | Base | 133 | 162 | 198 | 243 | 365 | 549 | 793 |
| | LCD Option | 133 | 162 | 198 | 243 | 365 | 549 | 793 |
| Togo | Base | 180 | 133 | 133 | 132 | 130 | 128 | 127 |
| | LCD Option | 180 | 195 | 223 | 256 | 335 | 438 | 558 |

**Table 5: Emission projection from generated electricity**

| Country | 2015 | 2025 | 2035 | 2045 | 2055 | 2064 |
|---|---|---|---|---|---|---|
| Benin_Base | 226,100 | 185,959 | 211,318 | 240,135 | 272,881 | 306,154 |
| Benin_LCD | 271,320 | 285,769 | 387,195 | 524,617 | 710,814 | 934,283 |
| Burkina_Base | 280,384 | 219,006 | 239,190 | 261,235 | 285,311 | 308,871 |
| Burkina_LCD | 336,461 | 338,621 | 441,564 | 575,803 | 750,851 | 953,468 |
| CDV_Base | 1,124,299 | 871,223 | 890,825 | 910,868 | 931,362 | 950,201 |
| CDV_LCD | 1,349,159 | 1,323,769 | 1,614,082 | 1,968,063 | 2,399,674 | 2,868,496 |
| Ganbia_Base | 94,182 | 66,948 | 61,158 | 55,869 | 51,037 | 47,047 |
| Gambia_LCD | 113,018 | 101,326 | 110,511 | 120,528 | 131,453 | 142,129 |
| Ghana_Base | 2,134,793 | 1,755,796 | 1,995,228 | 2,267,311 | 2,576,496 | 2,890,654 |
| Ghana_LCD | 2,561,752 | 2,698,184 | 3,655,822 | 4,953,344 | 6,711,383 | 8,821,332 |
| Guinea_Base | 273,443 | 213,584 | 233,269 | 254,768 | 278,248 | 301,225 |
| Guinea_LCD | 328,132 | 330,238 | 430,633 | 561,549 | 732,265 | 929,866 |
| GuBis_Base | 56,727 | 43,958 | 44,947 | 45,958 | 46,992 | 47,943 |
| GuBis_LCD | 68,073 | 66,792 | 81,440 | 99,300 | 121,077 | 144,732 |
| Liberia_Base | 38,472 | 30,050 | 32,820 | 35,844 | 39,148 | 42,381 |
| Liberia_LCD | 46,166 | 46,463 | 60,588 | 79,007 | 103,025 | 130,827 |
| Mali_Base | 149,490 | 110,531 | 104,188 | 98,210 | 92,574 | 87,779 |
| Mali_LCD | 179,388 | 166,577 | 187,260 | 210,512 | 236,650 | 262,937 |
| Niger_Base | 318,737 | 236,206 | 233,207 | 230,246 | 227,322 | 224,723 |
| Niger_LCD | 382,484 | 360,709 | 425,192 | 501,203 | 590,801 | 685,057 |

**Table 6: Results of running the EP-LCDv1 Model at different CF and EF respectively**

| | Scenario | 2015 | 2064 | Difference 50 |
|---|---|---|---|---|
| | | Million $tCO_2$ | | |
| | Base (A) | 15.28 | 20.9 | 5.62 |
| LCD Options | LCD-CF0.5 > Base_EFBase (B) | 22.93 | 71.37 | 48.44 |
| | LCD-CF0.5 > Base_EF0.3 < Base (C) | 18.34 | 57.1 | 38.76 |

corresponding increase in emission as shown in Table 6. Still on Table 6, for LCD Option 2, when the average emission released from these plants were improved upon through across board 30% reduction in the emission factors, a reduced emission was achieved compared to merely improving the capacity factor. The energy generated in both alternatives, however, were similar. These two low-hanging alternatives analyzed were fist identified as high leverage points from conducting the base run simulation.

The strategic intervention examined is for improved capacity and emission factors respectively. All other identified parameters are kept at their Base run values. For the electricity sector, this intervention is seen as low hanging option to address the trade-offs between economic development and emission reduction as options for targeting low carbon economy in West Africa. The possible barriers to achieving this intervention include but not limited to the following: (1) not being ready to promote the technical knowhow needed to achieve desired improvement in the capacity and emission factor levels amongst the existing power generation technologies across the nations in WAPP; (2) not willing to incentivize the sector to attract potential investors and innovators with adequate reward. Innovation means practices amongst the stakeholders in the WAPP system that generate electricity, to have desirable features in line with global emission reduction objectives, as in the Paris Agreement.

To estimate the cost impact, only existing technologies were examined without taking into consideration environmental factor improvement such as carbon capture storage alongside the generation technology. Further, the estimate of cost impact was based on an across board average having combined the overnight cost [42, 43] for all existing generation technologies in West Africa, namely, oil, natural gas, coal and hydro.

The cost impact was calculated based on construction of new power plants. Factors determining cost of electricity from new power plants include construction costs, fuel expense, environmental regulations, and financing costs. Other factors that drive power plants cost are government incentives, air emissions control on coal and natural gas.

Figure 4 is the mini model developed to assess the cost impact of these trade-offs. It was assumed that compounded annual initializing (growth) rate and compounded annual scraping rate in the system will be 6% and 1.5% respectively. Cost values were taken from [37, 38]. Table 7 shows the cost impact for 2064. Total cumulative cost impact is approximately US$1.54 trillion from 2018 through to 2064. The cost impact was limited to capital, financing and fuel costs [42, 43] to estimate what is needed to achieve trade-offs in the WAPP system. This means that the total cost will be significantly higher than what is estimated here.

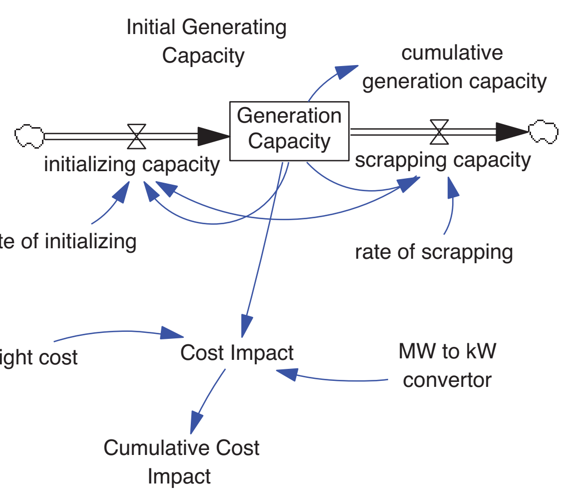


Figure 4: Cost impact assessment model for WAPP energy-climate change trade-offs

It is pertinent to point out that the cost estimates are based on OECD standard. The cost of this same technologies from other regions may be more competitive. Now, the existing mix of generation technologies in the WAPP system consists of oil-fired, natural gas, coal and hydro plants. The generators are not new and they have aged, and over the years, have been affected by changes in technology and economics. Indeed, most of the plants in the WAPP system have units that were built decades ago as base-load stations. Though most of them are still operated as base-load*, they are best supposed to operate as cycling or peaking plants because high fuel prices and poor efficiency has made them economically marginal. This implies that the regional organization will need to get the government of WAPP member nations involved to incentivize the strategic intervention process to for LCDS.

The government in this region must decide to deliberately influence the factors affecting cost of electricity to determine the kind of improvement that could be achieved in existing plants and/or power plants that would be built in the future. First of such approach would be to encourage the policy of energy efficiency through technology improvement with increased capacity factor and decreased energy intensity of economic activities that will also mean reduced emission factor. To encourage energy efficiency and decrease energy intensity of economic activities will both require increased spending on research and development on the part of government. This is currently non-existent in the West African region. Second strategy should be aimed at incentivizing construction of power plants to especially benefit base-load plants such as those that will encourage emission reduction, which are costly to build. The third approach which will be short term, say in a five year period, that will allow low carbon fuels (principally, natural gas) cost to benefit intermediate load plants as a transition

**Table 7: Cost impact of generation capacity in the WAPP system in 2064**

| Technology/ Fuel Type | Overnight Cost, $/kW (2012$) | Capacity in 2064, MW | Cost implication, US$, Billion |
|---|---|---|---|
| Oil-Fired | 1200 | 4027 | 4.84 |
| Natural Gas | 1023 | 13,970 | 14.30 |
| Coal | 3246 | 91.4 | 0.30 |
| Hydro | 2936 | 10,740 | 31.54 |
| Total | | | 50.98 |

*Sources: [42, 43]*

* **Base-load** plants such as nuclear, coal, and geothermal base-load units, are expensive to build but have low fuel costs and therefore low variable costs. Other than for planned and forced maintenance, these generators will run throughout the year. **Intermediate load** plants, such as combined cycle units, are very efficient but use expensive natural gas as a fuel. These cycling plants will ramp up and down during the day, and will be turned on and off dozens of times a year. **Peaking load** plants, use combustion turbines and are relatively inefficient and burn expensive natural gas. They run only as needed to meet the highest loads.

process; these category of power plants are inexpensive to build but rely on an expensive fuel. This is to encourage a quick ramp up of generation capacity to increase economic dispatch in the grid system. These strategies should however be reviewed periodically in line with determination to meet Paris Agreement on NDC for these nations.

## 5. Summary and Conclusion

The central focus of this article is to present a developed SD model for assessing the WAPP electricity system behavior in a low carbon economy. Its principal aim is to eliminate the usual trial and error approach that characterizes policy formulation, which are usually costly and time consuming. The model presented – is adopted and modified Electricity Planning-Low Carbon Development (EP-LCD) [2] – consists of the following modules: socio-economic, electricity and LCD Option. The socio-economic module consists of variables and parameters on population and GDP; the electricity module has electricity marketing, capacity addition, power demand and LCD Option has $CO_2$ emission estimation from electricity generation activities. For this study, the most critical sector is the capacity addition, which was linked to emission assessment from electricity generated in the system.

The structure of the model was first established to ascertain the model behavior, this was followed by unit checks; the model was calibrated using values for the parameters in the mode. The data used were from WAPP. High leverage points were identified after the Base run simulation was done. Comparing results of the two scenarios: Base Case run revealed the high leverage points in the model that was used to conduct the and LCD Option runs.

The high leverage points are: capacity factor, adjustment time for capacity, expectation formation and emission factor. The first three are directly or indirectly relevant to capacity addition and energy generated while the last one has relevance with emission. High leverage points are variables within the West African electricity system that are small yet could produce desired low carbon development strategy as identified in the simulation and help to situate firming of intervention for reducing environmental footprint from electricity production.

The results from the model shows weighted average emission of harmful GHG to the atmosphere was 27.1 million $tCO_2$ equivalent for the Base Scenario, while for the two *LCD* Options, the average weighted average annual emissions is 31.5 and 15.8 million $tCO_2$ equivalent respectively. The cumulative emission for the scenarios are 1.4, 2.2 and 0.8 billion $tCO_2$ respectively. Adopting an improved capacity factor for the existing power generation stocks and a reduced emission factors achieved marked reduction in emissions over the years. Estimated cost impact is approximately US$1.54 trillion from 2018 through to 2064. The cost impact of *increasing generation capacity in the LCD Option* was limited to capital, financing and fuel costs, meaning that the total cost could significantly higher than this.

The study noted that most generators in the WAPP system have aged. They have been affected by changes in technology and economics. Indeed, most of the plants in the WAPP system have units that were built decades ago as base-load stations. Though most of them are still operated as base-load, they are best supposed to operate as cycling or peaking plants because high fuel prices and poor efficiency has made them economically marginal. The implication is that government incentives are needed to drive the process of avoiding the trajectory of industrial era in West Africa nations. A number of countries in the region have privatised their power industry. Thus government decisions to influence, or not influence, the factors affecting cost of electricity can largely determine the kind of improvement that would happen in the existing generation plants and/or power plants that would be built in the region in the future. Three of such strategies are recommended to cause improvement in existing power plants in line with Paris Agreement, reduce the cost of constructing power plants to benefit base-load plants and reduce the cost of fossil fuels to benefit intermediate load plants in the short run period to allow the ramp up of generation capacity. These should be done from between 2018 and 2030 to incentivize the market.

The study concludes by recommending four strategies to encourage the implementation of energy efficiency policies, in line with the Nationally Determined Contribution in Paris Agreement. These are: a) enforcement of improved efficient electricity generation through increased energy efficiency that should result in increased capacity factor. This could be achieved through incentivizing retrofitting process; b) decreased energy intensity of the economy that should result in reduced emission factor amongst existing plants. This strategy involves rehabilitation of the existing installations to elongate the lifespan of aged power plants in improved forms; c) attract new investment through low tax or tax exemption to reduce cost of constructing power plants for the benefit of base-load plants. This is to attract investment in new generations that encourage low carbon economy in the WAPP system; and d) subsidized cost of low-carbon fuels in the short run to benefit intermediate load plants and allow for the ramping up of low-/no-carbon fuel generation capacity. This is considering that construction of new power generation facilities and transmission lines require much more substantial resources than improving on their rehabilitation. These approaches are recommended considering the region's specific economical and political conditions; funds are tremendously difficult to raise [25]. Implementing these recommendations will allow the electric power industry in West Africa to contribute to achieving sustainable development path.

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